Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Request by Echodyne Corp. for Waiver of Section 2.106 and Sections 87.471 and 87.475 of the Commission's Rules	)))	File No. ____________

ACCEPTED/FILED

DEC 14 2017

Federal Communications Commission
Office of the Secretary

To: Chief, Office of Engineering and Technology
Chief, Wireless Telecommunications Bureau

REQUEST FOR LIMITED WAIVER

Pursuant to Section 1.925 of the Commission's Rules,[1] Echodyne Corp. (Echodyne) hereby seeks limited waiver of the U.S. Table of Allocations and the rules applicable to Aviation Services under Part 87 of the Commission's Rules in order to deploy ground-based radar transmitters in the 24.45-24.65 GHz band for various radiolocation applications. Grant of this request will serve the public interest by allowing deployment of small size radars that will enhance the safety and security of the American public.

I. Background.

Echodyne is a technology startup company headquartered in Bellevue, Washington, and backed by Bill Gates, Vulcan Capital, NEA, Madrona Venture Group, Lux Capital, and The Kresge Foundation, among others. Echodyne is enabling innovative uses of radar technology by developing high performance, and ultra-low cost, size, weight, and power (C-SWaP) electronically scanning radars. Its Metamaterial Electronically Scanning Array ("MESA") offers disruptive capabilities for existing radar applications and enables new categories of radars for unmanned aerial systems (UAS), robots, autonomous vehicles, and security.

---

[1] 47 C.F.R. § 1.925.

Echodyne's MESA is a major breakthrough in radar technology because it is thinner, lighter, and less expensive than any other electronically scanning radar device. MESA is far easier to deploy than other radar devices because it is one-tenth the cost and weight of a standard C-Swap radar and an antenna one-fifth the size of a traditional electronically scanned array.

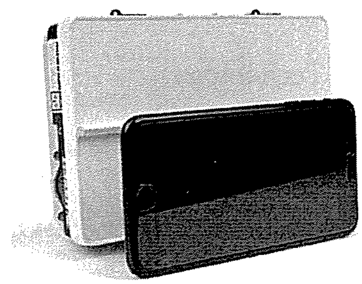


Fig. 1: MESA-DAA Radar next to a smartphone

Echodyne's first commercial product is an electronically scanning airborne detect and avoid (DAA) radar called MESA-DAA. MESA-DAA was designed to have ultra-low C-SWaP so it could be installed on small and medium-sized UAS to aid navigation and avoid collisions. MESA-DAA is currently awaiting a grant of certification under the FCC's equipment approval program. While Echodyne originally intended the MESA to operate only as an airborne DAA device, both government (Federal and non-Federal) and commercial companies have expressed tremendous interest in using the device for ground-based activities, including both ground-based DAA and ground-based security and surveillance radar (SSR). This interest has been so strong that Echodyne has created a version of the radar optimized for ground-based use, the MESA-SSR. The radio componentry of the MESA-SSR is identical to the MESA-DAA, however, the MESA-SSR has slightly higher RF power output (26 dBW EIRP vs. 24 dBW EIRP) and a shorter chirp duration in its waveform.[2]

[2] *See* Appendix A for more technical details on the MESA-SSR radar.

Echodyne's MESA-SSR radar is an attractive solution for ground-based DAA systems such as the UAS Traffic Management (UTM) system being developed by the Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) to provide air traffic control for UAS. Two of the FAA's UAS Test Sites will be using MESA-SSR in their next phase of UTM testing for NASA. One of these test sites previously tested MESA-DAA for airborne use under Echodyne's experimental license.[3] Based on the results of those tests, they selected MESA-SSR as a potential ground-based sensor for UTM.

MESA-SSR is also an attractive solution for drone detection and security. The FAA has recognized the urgent need for drone detection and security solutions, and has been instructed by Congress to evaluate UAS detection systems at airports and other critical infrastructure sites.[4] The FAA's Pathfinder Program is focused on testing and evaluating drone detection systems at airports. The FAA is seeking drone detection solutions for other critical infrastructure through cooperation with federal partners, including the Department of Homeland Security; the Department of Defense; the Federal Bureau of Investigation; the Federal Communications Commission; Customs and Border Protection; the Department of the Interior; the Department of Energy; NASA; the Department of Justice; the Bureau of Prisons; the U.S. Secret Service; the U.S. Capitol Police; and the Department of Transportation.

Echodyne itself is working with U.S. Customs and Border Protection and Defense Advanced Research Projects Agency (DARPA) on drone detection and security projects, and has many commercial customers that would like to use MESA-SSR for drone detection around the perimeters of high-value sites such as prisons, stadiums, amusement parks, and industrial

---

3 The call sign for Echodyne's experimental license is WI2XKY.

4 *FAA Evaluates Drone Detection Systems at DFW*, April 28, 2017, *available at* https://www.faa.gov/news/updates/?newsId=87949.

facilities. At the request of customers, Echodyne has demonstrated MESA-SSR at several of these high-value sites and has proven its effectiveness at providing advance notice of intruding drones. For example, Echodyne participated in a demonstration at a prison that showed how MESA-SSR can alert prisons to drones carrying contraband so guards can intercept delivery of the contraband.

Echodyne's radar is designed to operate in the 24.45-24.65 GHz band. Under Section 2.106 of the Commission's rules, that band is allocated for primary Federal and non-Federal shared use for inter-satellite communications and radionavigation services.[5] When MESA-DAA is used on a UAS or when MESA-SSR is used as part of a ground-based air traffic control system, each application meets the definition of "radionavigation" under the ITU definition that has been incorporated into the Commission's rules and, therefore, complies with the current allocation.[6] However, if the same radar device is installed on the outer wall of a prison to monitor for intruding drones, that application better meets the definition of "radiolocation."[7]

Therefore, a radar that detects drones and communicates that information for navigation purposes is treated differently than the same radar that detects drones and communicates that information for security purposes, even when both are similarly installed at a fixed location on the ground. While Echodyne believes that, in this case, from a practical and technical

5 International footnote 5.533 applies to the band, which states that "[t]he inter-satellite service shall not claim protection from harmful interference from airport surface detection equipment stations of the radionavigation service." *See* 47 C.F.R. § 2.106.

6 47 C.F.R. § 2.1 (defining radiodetermination as "[t]he determination of the position, velocity and/or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation properties of radio waves" and defining radionavigation as "[r]adiodetermination used for the purposes of navigation, including obstruction warning").

7 47 C.F.R. § 2.1 (defining radiolocation as "[r]adiodetermination used for purposes other than those of radionavigation"). By definition, radionavigation and radiolocation are both a subset of radiodetermination.

perspective, the distinction between the two types of radiodetermination – *i.e.,* radionavigation and radiolocation – is not material, the rules require that the FCC must grant a waiver of the table of allocations and attendant rules in order for the MESA-SSR to be used for security applications.

For non-Federal Government users, the band is available under Part 87 (Aviation Services) of the FCC's Rules. Section 87.173 of the Commission's Rules provides that the band is available for aircraft and land stations for aeronautical radionavigation purposes. Subpart Q of Part 87 likewise specifies that land-based stations are limited to aeronautical navigation, including obstruction warning. Finally, Echodyne has reviewed all available sources and has not been able to identify any Federal or non-Federal assignments within this 200-megahertz band.

II. Request for Waiver.

The Commission may grant a waiver of its rules if good cause is shown.[8] More specifically, the Commission may grant a request for waiver if it is shown that: (i) the underlying purpose of the rule(s) would not be served or would be frustrated by application to the instant case, and that a grant of the requested waiver would be in the public interest; or (ii) in view of unique or unusual factual circumstances of the instant case, application of the rule(s) would be inequitable, unduly burdensome or contrary to the public interest, or the applicant has no reasonable alternative.[9] As discussed below, Echodyne believes that grant of its waiver request would better serve the underlying purpose of the rules and is in the public interest, including the interests of aviation, public safety and security.

---

[8] 47 C.F.R. §1.3.

[9] 47 C.F.R. § 1.925.

Echodyne has identified three FCC rules that appear to restrict use of MESA-SSR as a radiolocation radar useful for drone detection and general vehicular tracking:

- Section 2.106 specifies that the band is allocated for radionavigation services.
- Section 87.471 specifies that transmission by land stations must be limited to aeronautical navigation, including obstruction warning.
- Similarly, Section 87.475 (b)(14) provides that in the band, land-based radionavigation aids are permitted only where they operate with airborne radionavigation devices.

As stated, Echodyne believes grant of its waiver request will not undermine the fundamental purposes of the aeronautical radionavigation allocation and is in the public interest. However, to alleviate any concerns regarding long-term operation of the MESA-SSR under this waiver, Echodyne proposes that the Commission include the following conditions on any waiver:

- ***Secondary Status***: Echodyne recommends that stations authorized pursuant to the requested waiver have secondary status and, therefore, must not cause interference to primary users and must accept any interference received from other authorized users.
- ***Term***: Echodyne would prefer that stations authorized pursuant to these waivers would be granted a full 10-year license term with provisions for renewal.[10] However, Echodyne would agree to a limited term of 5 years that could be renewed if there are no unresolved instances of harmful interference caused by the MESA-SSR. Echodyne further proposes that the term of the waiver itself should be 10 years. After the waiver's term expires, no new non-Government stations would be authorized under the terms of the waiver but stations authorized prior to that date could continue to operate pursuant to their FCC license. During this 10 year term, Echodyne would pursue a rulemaking proceeding to allow such use on a permanent basis.
- ***Limited Number of Units***: Echodyne would agree to limit the number of units that could be authorized under the waiver to a total of 20,000 individual stations/radar units during the first 5 years of the waiver.[11] After 5 years, Echodyne proposes that this limitation be removed for the remaining term of the waiver provided that there are no unresolved instances of harmful interference due to the MESA-SSR.

---

[10] 47 C.F.R. § 87.27 provides for a 10-year license term for stations in the aviation services.

[11] Note that a security installation would deploy multiple radar units around its perimeter so the actual number of sites would be far fewer than 20,000.

- ***License Required*:** Echodyne recognizes that, as fixed stations in the aviation services, ground-based stations authorized pursuant to this waiver would be subject to the relevant FCC application and licensing processes.

- ***Equipment Approval Requirement*:** Echodyne would seek equipment approval for the MESA-SSR under the same technical requirements as for the MESA-DAA.

As further explained below, grant of the waivers under these conditions satisfies the Commission's public interest standards for regulatory relief.

III. Grant of the Requested Waivers Would Serve the Public Interest.

Section 1.925 of the Commission's Rules allows the Commission to grant a request for waiver if it is shown that: (i) the underlying purpose of the rule(s) would not be served or would be frustrated by application to the instant case, and that a grant of the requested waiver would be in the public interest; or (ii) in view of unique or unusual factual circumstances of the instant case, application of the rule(s) would be inequitable, unduly burdensome or contrary to the public interest, or the applicant has no reasonable alternative.[12]

Echodyne's request for waiver satisfies both alternative prongs of the Commission's waiver standard. First, the underlying purpose of the rules would be frustrated by application to this case. As previously noted, Part 87 of the Commission's rules already allows both airborne and fixed ground-based use of the 24.45-24.65 GHz band for radionavigation. When MESA-SSR is used as part of a ground-based air traffic control system, the radar detects UAS and then relays the information to assist in navigation. Echodyne proposes to use the same radar as a ground based security system. In this use case, the radar would also detect UAS, but it would not relay the information for navigation. In both instances, it is the same radar, located in the same location, providing an aviation-related use in a band allocated for aviation. Furthermore, in both cases the radar is providing an important public safety function, which is another underlying

12 47 C.F.R. § 1.925.

purpose of the rule. Clearly, treating similarly situated radars differently under the rules would be inequitable, and the underlying purpose of the Commission's Part 87 rules would be frustrated by unduly rigid application of the rule.

Second, grant of the instant waiver request is in the public interest, as it would enable users to deploy the radar in order to enhance public safety and protect critical infrastructure and other key assets. In granting the waiver, the Commission would help the FAA fulfill Congress's mandate to find drone detection and security solutions to protect, among other things, critical infrastructure.

Drone detection, Echodyne's primary application for land-based radiolocation stations, is a direct public safety application. Federal agencies are interested in using the technology for homeland security measures to protect U.S. borders. Stadium operators are interested in using the technology to protect the public located in vulnerable open spaces. Prison officials want to use the technology to help intercept the delivery of contraband material into prison yards. Echodyne's MESA-SSR radar is the ideal solution for these use cases given its small size and relative low cost. In addition, there are few equally effective and economical alternative solutions. Rejecting the waiver request would be contrary to the public interest because it would delay – and could prevent – Echodyne and its partners from enabling Federal and non-Federal users to address these important public safety and security needs.

Finally, application of the existing rules to Echodyne's unique MESA-SSR radar would be unduly burdensome. Echodyne has developed state-of-the-art technology that serves a variety of public interest applications in a band that lies fallow. There are no current licensed or authorized systems deployed in the band. The primary application for Echodyne's technology – airborne and ground-based DAA radar – is fully consistent with the Table of Allocations and existing Part 87 rules and will be key to allowing commercial UAS to fly beyond line of sight in the national air space in a safe manner. At the same time, as already described, the identical device can easily meet a variety of public safety and security applications required by both Federal and non-Federal users. It would be not only unnecessary but unduly burdensome to require Echodyne to redesign its equipment to operate in another frequency band.[13]

The Commission has permitted non-conforming uses of spectrum in the past,[14] and has noted that company-specific waivers of the Table of Allocations "are neither prohibited nor particularly unusual."[15] More specifically, the Commission has granted waivers of the Table of Allocations codified in Section 2.106 of the Rules, provided that (1) the proposed use has little

---

[13] There are only two other radiodetermination bands that are technologically suited for a MESA radar for ground-based surveillance, and only one of those bands overlaps with the frequency range best suited for airborne DAA. The 24.45-24.65 GHz band used by MESA-DAA and MESA-SSR is the most technologically suitable band available, and it unlocks great economies of scale by allowing Echodyne to build a single device that can serve multiple purposes.

[14] *See e.g.,* Qualcomm, Inc., *Memorandum Opinion, Order and Authorization*, 4 FCC Rcd 1543 (1989) (*Qualcomm OmniTRACS License*) (authorizing LMSS on a secondary basis in the 14 GHz band and on a non-conforming basis in the 12 GHz band); Mobile Satellite-Based Communications Services by Crescomm Transmission Services, Inc. and Qualcomm Incorporated, *Order*, 11 FCC Rcd 10944 (Int'l Bur./OET 1996) (*Crescomm/Qualcomm Order*) (authorizing non-conforming MMSS operations in the 14 GHz and 12 GHz bands); Fugro-Chance, Inc., *Order and Authorization*, 10 FCC Rcd 2860, 2860 ¶ 2 (Int'l Bur. 1995) (authorizing non-conforming MMSS in the C-band); *see also* Motorola Satellite Communications, Inc., *Order and Authorization*, 11 FCC Rcd 13952, 13956 ¶ 11 (Int'l Bur. 1996) (authorizing service to fixed terminals in bands allocated to the mobile-satellite service).

[15] In the Matter of Reconrobotics Inc., *Order on Reconsideration,* WP Docket No. 08-63, 26 FCC Rcd 5895 (2011) at ¶ 7.

potential to cause interference to licensed users in the band,[16] and (2) the entity accepts any interference from authorized primary and secondary licensed users.[17] Echodyne's proposed deployment of MESA-SSR for drone detection and security purposes satisfies these standards.

With respect to interference, we reiterate that there appears to be no licensed or authorized use of the band at this time. Also, even if there were in-band incumbents, Echodyne's MESA radars are highly compatible with other co-channel spectrum users. The Echodyne MESA-SSR is a low-power, frequency modulated continuous wave (FMCW) radar with a minimal transmission footprint, especially compared to traditional radars. The operational range for the device is approximately 3 kilometers, and it operates by rapidly scanning the field of view with a narrow "pencil-beam."[18] This pencil-beam scanning means the radar inherently has a very low probability of causing interference to other systems. In addition, Echodyne uses orthogonal FMCW waveforms for the airborne and ground-based versions of the radar. The airborne MESA-DAA sweeps up in frequency, and the ground-based MESA-SSR sweeps down in frequency. This significantly reduces the potential for interference between the airborne and ground-based services.

---

16 In the Matter of Reconrobotics, Inc., *Order,* 25 FCC Rcd 1782, 1784 at ¶ 7 ("[w]e note that one purpose of allocating different spectrum bands to different services is to prevent harmful interference.").

17 In the Matter of The Boeing Company *et al.*, *Order*, 16 FCC Rcd 22645, 22651 at ¶ 12 ("In considering request for non-conforming spectrum uses, the Commission has indicated that it would generally grant such waivers 'when there is little potential for interference into any service authorized under the Table of Frequency Allocations and when the non-conforming operator accepts any interference from authorized services.'").

18 *See* Appendix A for more technical details on the MESA-SSR radar.

The radars also use multiple channels to further reduce any chance of causing interference between the airborne and ground-based services, and mutual interference among the units in each service. In the absolute worst case, two MESA radars can operate on the same channel within 250 meters of each other while facing each other or intersecting each other's field of view and not cause interference at a confidence level of 99.8 percent. When separation between devices is held at 250 meters or greater, as many as 16 radars per square kilometer can operate without interference, and if the separation distance is further increased to 500 meters, the confidence in non-interference increases to 99.9%.[19]

The drone detection and security deployment also has little potential to interfere with adjacent band operations. The airborne MESA-DAA radar has been submitted for equipment approval and has shown that its emissions comply with the relevant limitations to protect any adjacent band operations.[20] The MESA-SSR radar that Echodyne wishes to use for security deployments will have the same emissions profile as the airborne MESA-DAA unit.

---

19 *See* Appendix B for a more detailed capacity and interference analysis.

20 The Echodyne MESA-DAA radar has been tested to show compliance with the emission limitations defined in Section 87.139(a).

IV. Conclusion.

Grant of the limited waiver relief requested herein would serve the public interest by enhancing public safety and security across the country without increasing the potential for harmful interference to other radio services. Echodyne urges the Commission, in coordination with other affected Federal Agencies to expeditiously review and approve this request for waiver.

Respectfully Submitted,

/S/ Edward "Smitty" Smith
Edward "Smitty" Smith III
Partner
DLA Piper, LLP

/S/ Andrea Radosevich
Andrea Radosevich
General Counsel
Echodyne Corp.

/S/ Michael A. Lewis
Michael A. Lewis
Senior Engineering Advisor
DLA Piper, LLP
500 8th Street, NW
Washington, DC 20004

October 27, 2017

Attachments: Appendix A
Appendix B

CC:
Julius Knapp
Chief
Office of Engineering and Technology

Ronald Repasi
Deputy Chief
Office of Engineering and Technology

Michael Ha
Deputy Chief, Policy and Rules Division
Office of Engineering and Technology

Donald Stockdale
Chief
Wireless Telecommunications Bureau

Roger Noel
Chief, Mobility Division
Wireless Telecommunications Bureau

Scot Stone
Deputy Chief, Mobility Division
Wireless Telecommunications Bureau

ECHODYNE

APPENDIX A: TECHNICAL DETAILS OF MESA-SSR RADAR

Performance

Operational range	3.4km
Range (vehicle)	>3km
Range (human)	>1.5km
Range (sUAV)	>750m
Field of view	≥120° Azimuth x 80° Elevation
Range resolution	3.25m
Angle resolution	±1º Azimuth x ±3º Elevation
Velocity resolution	0.9 m/s
Scan update rate	~1Hz for 120° Az x 20° El volume

SWAP

Size	20.3cm x 16.3cm x 4cm
Weight	1.25kg
Power	DC +9V to +32V
	Operating <45W
	Hot standby <10W
	Hibernate TBR <100mW

Emission

Frequency	24.45 - 24.65 GHz (Multi-Channel)
Emission Type	Frequency Modulated Continuous Wave (FMCW) with linear ramp
RF Power Output	24dBW EIRP
Channel Bandwidth	45 MHz

Transmitter Description

The transmitter is a solid state balanced pair of MMIC power amplifier devices set at a bias point to deliver +33 dBm (2000 mW) to the MESA-DAA. Transmit power is automatically blanked when radar is not being triggered to take data, or when radar is stopped.

Antenna Description

- Beam Shape: Azimuth 4° / Elevation 12° (Half power beam width) one way TX or RX which results in a radar two-way Azimuth 2° / Elevation 6° half power beam width.

- Beam Steps: 2° Azimuth x 8° Elevation. Used for full volume scanning while accepting some beam loss. Tracking can be smaller elevation steps down to 2°.

ECHODYNE

- Total Number of Beams: ~180 each with a dwell time of ~7-10mSec. This is based on radar data collection coherent process interval, typical field of regard, and the beam step size.
  - Total Beams = 60 Az beams x 3 elevation beams = 180
  - Probability of two beams exactly co-pointing while scanning = 100 x 1/180^2 = 0.003%
- Directivity: 21 dBi TX or RX antenna.

ECHODYNE

APPENDIX B: MESA Radar Interference Analysis

Background

The following analysis presents a capacity projection for the use of the 24.45-24.65 GHz band by Echodyne's MESA-DAA and MESA-SSR radar devices. The MESA-DAA radar is a small, lightweight electronically scanning radar designed to provide detect-and-avoid (DAA) capability on small unmanned aerial vehicles. The radar operates in the radionavigation frequency band at 24.45-24.65 GHz, using three channels of 45 MHz each. It is a frequency modulated continuous wave (FMCW) radar with peak power of 2 to 4 watts. There is also a version of the radar called MESA-SSR that is optimized to operate as a ground-based DAA/navigation radar or as a ground-based drone detection radar for security purposes.

MESA radars have three key features that protect against interference:

- Narrow pencil-beam scanning
- FMCW waveform
- Multiple channels

The most important of these is the narrow pencil-beam scanning. Many other radars use a wide beam that illuminates the full field of view – for example, digital-beam forming automotive radars or interferometric radars. Wide-beam radars need to use extraordinary methods to prevent interference. In contrast, narrow-beam radars like MESA inherently have a low probability of interference.

Summary of conclusions

1. **Interference between airborne DAA sensors**. Multiple airborne MESA-DAA can operate on the same channel in the same area without causing interference to each other. In the absolute worst case, two MESA-DAA can operate co-channel within 250 meters of each other while facing each other or intersecting each other's field of view and not cause interference at a confidence level of 99.8 percent. When separation between devices is held at 250 meters or greater, as many as 16 airborne radars per square kilometer can operate without interference and if the separation distance is further increased to 500 meters, the confidence in non-interference increases to 99.9%. We could achieve greater density in the future by adding more channels, waveform coding and synchronization.
2. **Interference between ground-based SSR sensors.** MESA-SSR can operate as a ground-based navigation or security radar at the same or higher densities than the airborne DAA sensor. The ground-based MESA-SSR radars will operate in known, fixed locations

and can be configured so they will not interfere with each other using directivity and channelization.

3. **Interference between airborne DAA and ground-based SSR sensors**. MESA-SSR can operate as a ground-based radar without causing any degradation to airborne DAA sensors, and vice versa. MESA uses orthogonal FMCW waveforms for the airborne and ground-based versions of the radar; the airborne MESA-DAA sweeps up in frequency, and the ground-based MESA-SSR sweeps down in frequency. This eliminates false signal interference and greatly reducing the potential for noise interference.
4. **Interference with other unknown devices operating in the 24.45-24.65 GHz band**. There are no other known devices operating in the 24.45-24.65 GHz band. Even if there were other users in the band, the potential for interference is low. MESA radars are low-power with a minimal transmission footprint, and they use multiple channels to further reduce their footprint.

Overview of interference

Interference in radar and communications devices is a stochastic problem of considering the possibilities that multiple factors will simultaneously align; *e.g.* the physical orientation of devices, the spectral channels of devices, the coding/filtering utilized on devices, and the attributes of the intentional radiator (*e.g.* antenna gain) at any one point in time. In extreme scenarios, all devices suffer from the possibility of causing or receiving interference. However, interference can be mitigated by using multiple configurations which possess some degree of orthogonality. Examples are utilization of different channels (frequency orthogonality), polarizations, transmit receive antenna patterns (spatial orthogonality), etc. Through this interference analysis, we consider the probabilistic extent to which MESA radars are likely to disrupt other MESA units and other unknown devices operating in the 24.45-24.65 GHz band.

Interference types: Noise vs false-signal

There are two types of interference that a radar can experience: noise injection, and false-signal injection.

- Noise injection. Noise injection is the more common type of interference in radars. It has only a small effect on the operation of the radar, typically resulting in mild loss of sensitivity and reduction of effective operational range. Noise injection can result from true noise sources, or from out-of-band / incoherent signals which blur or alias back into the receiver bandwidth.
- False-signal injection. False-signal injection, which is the appearance of false (or 'ghost') signals, rarely happens in radars because it requires the simultaneous coincidence of many factors. Any time one or more of these factors do not line up (for example, the interfering signal is incoherent with the local oscillator, and/or has low correlation with

the receiver matched filters), the interfering signal will appear as noise injection rather than as a false-signal. In MESA radars, false signals are mitigated through the use of frequency-domain channels and time-domain sub-channels, and identification and resolution of channel-conflicts.

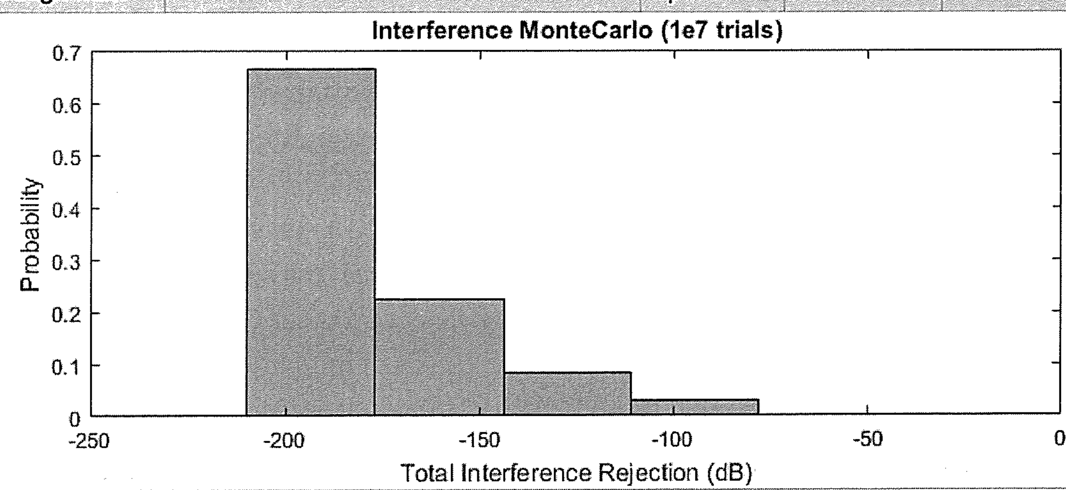
MESA to MESA: Spatio-spectral interference rejection

MESA radars were designed with multiple overlapping interference mitigation methods. The heart of this is Echodyne's highly-directive MESA antenna technology with beam-steering on transmit and receive. The MESA antenna has very low potential for interference because it points a small pencil beam of transmit energy only in the direction the radar is interrogating, and it strongly rejects energy into the receiver from all other directions. This creates natural spectral hygiene and interference resistance, offering as much as 50dB (100,000 times) better interference mitigation than systems without beam-steering capability.

Secondly, MESA uses low-power FMCW with a linear ramp, a tried-and-true radar method for eliminating high peak-spectral-mass points which are the worst offenders for causing interference. These two approaches are combined with channelization (three 45MHz channels) and sub-channelization (chirp-timing) to achieve a system with multiple overlapping interference filters (both spectral and spatial). Table 1 below summarizes these factors, and gives Monte Carlo results for probabilistic total interference rejection.

Table 1 - DAA interference rejection parameters

Parameter	Description	Rejection domain	Interference rejection	Rejection reliability
Channel Selection	Utilization of separate channels, which can be selected in real-time. 3 channels planned at initial launch.	Spectral	-100 dB	66% (random ch) 100% (de-conflicted)
Inter-chirp timing	Adjustment of the chirp-to-chirp timing.	Spectral	-60dB	80%
Intra-chirp timing	Adjustment of the intra-chirp timing.	Spectral	-20dB	80%
Tx *and* Rx alignment	Use of highly directional MESA antenna.	Spatial	-50dB	98.30%
Tx *or* Rx alignment	"	Spatial	-25dB	99.99%



The advantages of this multi-level approach are evident in the results histogram: very high levels of rejection are achieved in the vast majority of encounters, with diminishingly small statistical chance for little/no rejection.

Scalability. The table below presents a signal to interference plus noise (SINR) cascade for MESA-DAA, looking at the interfering noise and signal levels for a known MESA-DAA interferer as a function of range. The key output specification is the SINR rejection requirement, the interference rejection threshold at/beyond which the operating SNR of MESA-DAA is reduced by 3dB or less (a 3dB degradation in SNR amounts to ~15% reduction in effective range).

Table 2 - Interference RF cascade

DAA Cascade										
lambda	0.012	m								
Signal Power	33	dBm								
Directivity (Tx)	25	dB								
Gain (Tx)	22	dB								
EIRP (peak)	55	dBm								
EIRP (RMS)	30	dBm								
Gain (Rx)	22	dB								
$\lambda^2/(4\pi)^3$ (*RRE constant*)	-71.2349	dB								
Range	100	250	500	1000	1500	2000	2500	3000	4000	m
$1/R^4$	-80.0	-95.9	-108.0	-120.0	-127.0	-132.0	-135.9	-139.1	-144.1	dB
Received Signal (0dBsm)	-74.2	-90.2	-102.2	-114.2	-121.3	-126.3	-130.2	-133.3	-138.3	dBm
Chirp coherant gain	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	dB
Rx Signal (Processed, 0dBsm)	-59.2	-75.1	-87.1	-99.2	-106.2	-111.2	-115.1	-118.3	-123.3	dBm
Thernal NoiseFloor (no interference)	-127	-127	-127	-127	-127	-127	-127	-127	-127	dBm
Native SNR (self-noise)	67.8	51.9	39.9	27.8	20.8	15.8	11.9	8.7	3.7	dB
DAA-DAA Interference										
$\lambda^2/(4\pi)^2$ (*Friis constant*)	-60.24	dB								
Range	100	250	500	1000	1500	2000	2500	3000	4000	m
$1/R^2$	-40.0	-48.0	-54.0	-60.0	-63.5	-66.0	-68.0	-69.5	-72.0	dB
Signal injection	-23.2	-31.2	-37.2	-43.2	-46.8	-49.3	-51.2	-52.8	-55.3	dBm
SIR (Interference Ratio)	-35.9	-43.9	-49.9	-55.9	-59.5	-62.0	-63.9	-65.5	-68.0	dB
Noise injection (per 5kHz bin)	-56.4	-64.3	-70.3	-76.4	-79.9	-82.4	-84.3	-85.9	-88.4	dBm
SINR Rejection requirement	-70.6	-62.7	-56.7	-50.6	-47.1	-44.6	-42.7	-41.1	-38.6	dB
Probability (Monte Carlo)	≥ 98.0%	≥ 99.8%	≥ 99.9%	≥ 99.95%	≥ 99.99%	≥ 99.99%	≥ 99.99%	≥ 99.99%	≥ 99.99%	

This table depicts a sliding scale requirement: the closer an interferer is, the greater the rejection requirement is in order to continue un-degraded operation. Looking at the "SINR rejection requirement", it is clear that without any rejection, the desired radar return could be degraded by between 70 and 40 dB depending on range. To be confident of maintaining detection range in the presence of interference, the total mitigation must exceed the interference level by more than 10 dB. From the interference Monte Carlo analysis depicted in Table 1, it is clear that >90% of the time there is over 110dB of mitigation and >99% of the time there is at least 80 dB mitigation. This provides substantial margin at all ranges beyond 250m and likely even at 100m.

A worst-case analysis of this data describes the absolute floor on MESA-DAA user density. The data shows that with greater than 99.8% confidence, two users would be able to operate with zero interference while facing each other or intersecting each other's field of view with 17.3 dB of margin (80dB - 62.7dB = 17.3dB). In Table 2, the bottom row shows the actual confidence levels by range. As can be seen, confidence increases as range between potential users increases due to the R^2 effect of range and signal level. Effectively the problem gets easier by 6 dB for each doubling of the range from 250m out to 4000m.

Also, it is possible to use the margin above to estimate the number of additional non-coherent devices that could possibly co-exist together. While this is less conservative, it does give us a view into the future when MESA might use waveform coding and de-confliction management to enable greater density. So, given the 17.3dB of margin and subtracting 6dB for safety, we are left with 11.3dB of non-coherent power summation available.

$$Number\ Users = Intreger\ (10^{\left[\frac{Margin\ dB - Safety\ 5dB}{10}\right]})$$

Number = 13

While this represents the calculated number of possible adjacent radars from an electrical interference perspective, it does not consider the physical limits. Physically we are limited by a two-dimensional plane with a grid spacing of 250m. The maximum number of adjacent radars given this constraint is 9 devices. This supports 16 total radars spaced 250m over a square kilometer before additional coding or deconfliction is required.

MESA as an interferer to other devices

We reiterate that there appear to be no licensed or authorized users of the band at this time. Even if there were other users, the potential for interference is low. When considering the possibility of a MESA radar interfering with other unknown devices operating in the 24.45-24.65 GHz band, we do not need to consider false-signal injection because the receivers of other (non-MESA) devices will be incoherent with MESA (via LO oscillators, IF bandwidths, chirp rates, chirp timing, etc.), which eliminates the possibility of false signals. This is an advantage of using a spread spectrum approach like FMCW.

MESA's impact as a potential interferer is measured through its EIRP, and more specifically average (RMS) EIRP. Average EIRP accounts for the transmit beam-scanning, and the fact that any one device only experiences peak EIRP briefly and sporadically, when MESA is interrogating exactly in its direction (in azimuth and elevation). The RMS_EIRP of MESA-DAA is calculated in Table 2 above as +30dBm, which is a fairly weak radiator representing little more than a typical hand held cellular phone (Ref: https://en.wikipedia.org/wiki/DBm).

Coexistence of ground-based and airborne operation

The MESA-DAA hardware is designed for airborne operation, while MESA-SSR is designed for ground-based operation. While airborne platforms must maintain healthy separation from each other for aviation safety reasons, it may be common for airborne platforms to pass close to ground-based radar deployments. MESA eliminates the potential for interference in this scenario by using orthogonal waveforms for the airborne and ground-based versions of the radar, adjusting the direction of the chirp as follows:

- Airborne MESA-DAA software configures to mode A1, chirping up with 210us pulse repetition interval (PRI)
- Ground-based MESA-SSR software configures to mode B1, chirping down with 110us PRI.

This orthogonal-LFM coding ensures that there is baseline rejection in *all* (100.00% of) encounters, and completely eliminates the possibility of false-signal injection. The non-integer-ratio modification of PRI also increases the rejection reliability of the intra-chirp sub-channels when considering ground-based to air-borne interference (or vice-versa).

Table 3

Parameter	Description	Rejection domain	Interference rejection	Rejection reliability
Chirp U/D code	Air/Ground systems use orthogonal Up/Down chirps.	Spectral	-20dB	100%
Inter-chirp timing	Chirp-to-chirp autocorrelation A1:B1.	Spectral	-60dB	90%
Intra-chirp timing	Chirp-to-chirp autocorrelation A1:B1.	Spectral	-20dB	90%
Channel Selection	A1 mode: 3-ch w/ 210us PRT. B1 mode: 3-ch w/ 110us PRT (7-ch future planned).	Spectral	-100 dB	66% (random ch) 100% (de-conflicted)
Tx *and* Rx alignment	Use of highly directional MESA antenna.	Spatial	-50dB	98.30%
Tx *or* Rx alignment		Spatial	-25dB	99.99%

This modification ensures an isolation of at least 70dB (threshold for isolation at 100m from Table 2) to better than 99.99 (five-sigma), and allows for simultaneous operation of ground-based and airborne MESA radars in close proximity to each other.

The ground-based systems will always be non-interfering with the airborne systems regardless of whether the ground-based systems are used for air traffic control (radionavigation), security (radiolocation), or applications that blend radionavigation and radiolocation.

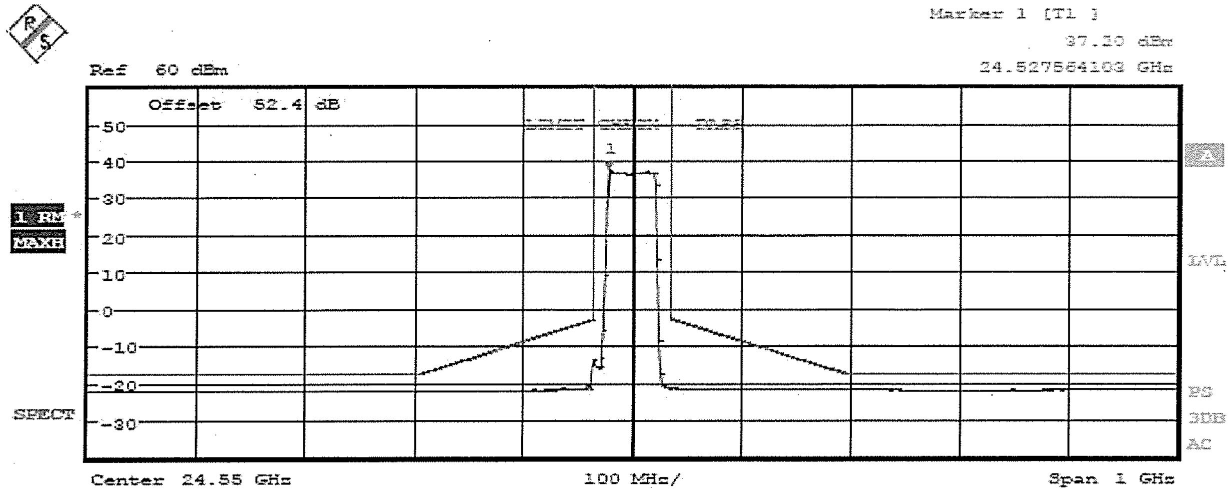
Echodyne Channelization Plan:

As previously described, Echodyne plans to implement a three-channel plan to subdivide the available 24.45-24.65 GHz band. This provides a high level of interference management in both airborne DAA applications with multiple air vehicles present, and in fixed installation ground based applications with multiple radars operating in close proximity. The channels are separated from each other, and stepped in from the ends of the band to prevent the primary emissions from extending beyond the designated 200MHz band. This includes all effects of frequency aging and offset tolerances. The Radar Spectrum Engineering Criteria (RSEC) Criteria A from Section 5.5.7.1 of the NTIA's Redbook, which Echodyne has used as a reference in its discussions with both the FCC and the FAA, is repeated here for reference.

Table 4 – RSEC Criteria A Mask and break points.

Mode A1 Parameter Settings	Setting
Center Frequency (Fo)	24550 MHz
Sweep Bandwidth B(FMCW)	45MHz
Sweep Time T(FMCW)	200uSec
Calculated Parameters	Value For Mask
B(-40dB)/2	34.90 MHz
B(-55dB)/2	196.27 MHz
X dB	-55 dB
Alpha	0.75

Figure 1 – Ref: Mask Overlay and Measured MESA-DAA from FCC Qualification Report



Tx Channel RSEC Criteria A

Bandwidth 1 MHz Peak Power 37.20 dBm

Start [Hz]	Stop [Hz]	RBW [Hz]	Freq [Hz]	PwrAbs [dBm]	PwrRel [dBc]	Δ Limit [dB]
-500.000 M	-196.270 M	1.00 M	24.195833 G	-22.21	-74.23	-4.40
-196.270 M	-34.900 M	1.00 M	24.354467 G	-22.45	-74.48	-4.65
34.900 M	196.270 M	1.00 M	24.743910 G	-21.94	-73.96	-4.35
196.270 M	500.000 M	1.00 M	24.747115 G	-21.89	-73.91	-4.08

Mid channel

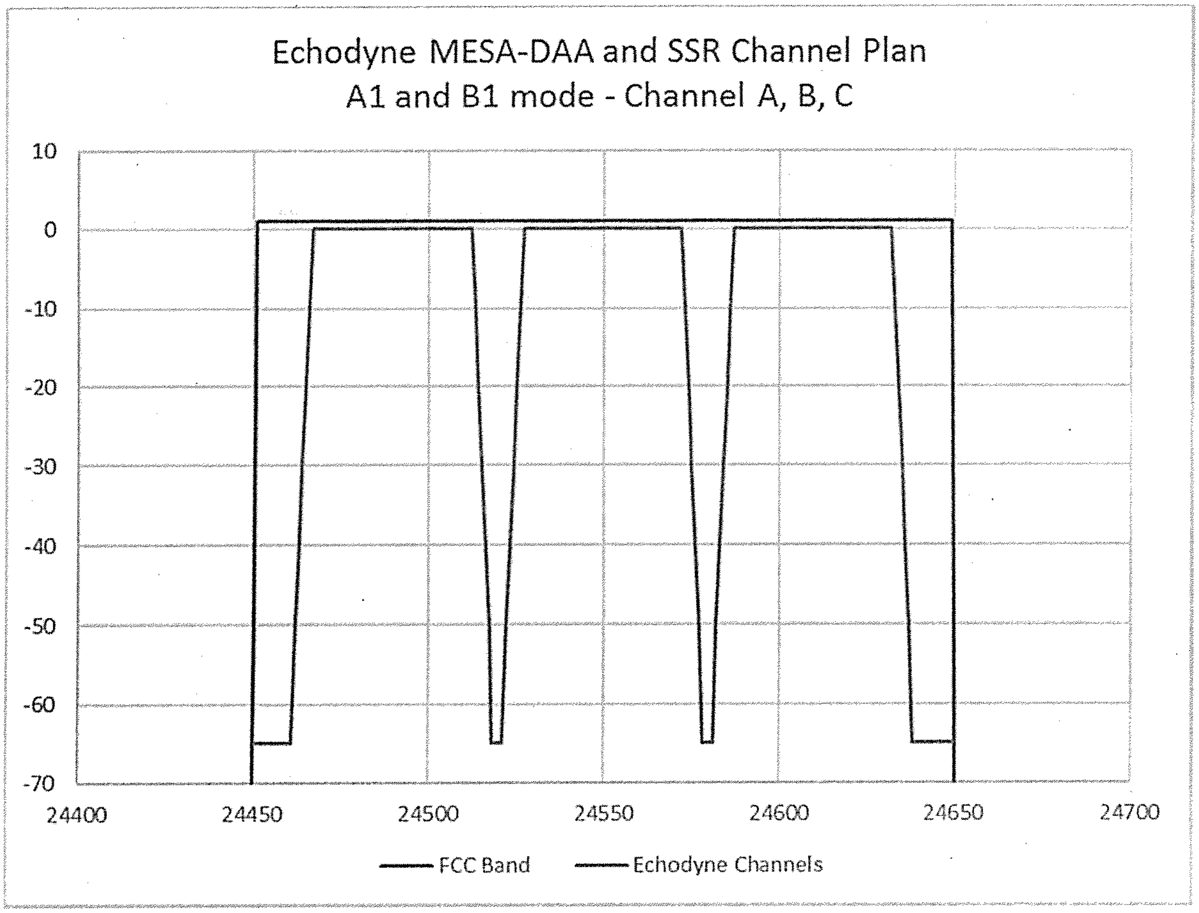
The measured emissions are greater than 10-15 dB below the mask's limits in all regions beyond the "chimney". This data is representative of all our modes. Echodyne's proposed frequency Channel plan and mask break points are as follows:

Table 5 - Channel Plan with Mask Margin Included

Descriptions	Frequency Points	Amplitude	Delta Fc MHz
Channel A1-A			
Lower -40dB Edge	24455.1	-40	34.9
Lower Operating Edge	24467.5	0	22.5
Center Channel	24490	0	0
Upper Operating Edge	24512.5	0	22.5
Upper -40dB Edge	24524.9	-40	34.9
Channel A1-B			
Lower -40dB Edge	24515.1	-40	34.9
Lower Operating Edge	24527.5	0	22.5
Center Channel	24550	0	0
Upper Operating Edge	24572.5	0	22.5
Upper -40dB Edge	24584.9	-40	34.9
Channel A1-C			
Lower -40dB Edge	24575.1	-40	34.9
Lower Operating Edge	24587.5	0	22.5
Center Channel	24610	0	0
Upper Operating Edge	24632.5	0	22.5
Upper -40dB Edge	24644.9	-40	34.9

This plan minimizes any possible spectral spread beyond the FCC designated band and leverages the waveform's tight adherence to the previously defined spectral mask. The channels as plotted below in Figure 2 show the planned 15 MHz between channels and 17.5MHz from each end of the band. Referring to Figure 1, one can see that the emissions within the two outer channels (Channel A1-A and Channel A1-C), would be approximately 65 dB down from the primary at more than 5 MHz away from their respective band edges, providing ample margin against the mask and eliminating channel-channel interference. The new B1 SSR mode would use the identical channel plan but would chirp DOWN (High-Low) as compared to the DAA that chirps UP (Low – High) to provide additional interference protection between ground radars and air radars. As previously mentioned, we expect to add more channels to the ground SSR radar in the future to facilitate multiple radars mounted in very close proximity.

Figure 2 – Visual Plot of Frequency Channel Breaks and Spectral Overlap


Echodyne MESA-DAA and SSR Channel Plan
A1 and B1 mode - Channel A, B, C
10
0
-10
-20
-30
-40
-50
-60
-70
24400
24450
24500
24550
24600
24650
24700
FCC Band
Echodyne Channels

* * * * *